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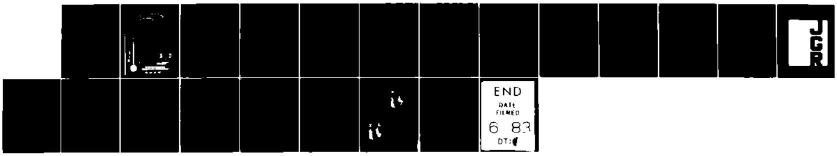

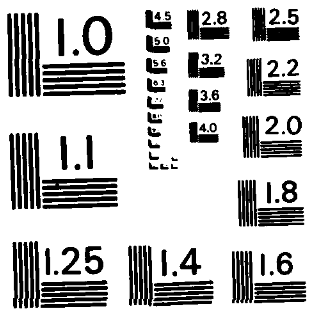

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Comparison of Heliospheric Current Sheet Structure Obtained from Potential Magnetic Field Computations and from Observed Polarization Coronal Brightness

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ABSTRACT

~~We~~ compares the structure of the heliospheric current sheet early in Sunspot Cycle 21 as computed from the observed photospheric magnetic field with a potential field approximation, and as inferred from synoptic maps of the observed coronal polarization brightness. On most of the solar rotations compared, the two methods give essentially the same results; the basic shape of the warped current sheet and the amplitude (in solar latitude) of the displacements of the sheet from the solar equator are similar. On one rotation the current sheet computed with the potential field approximation appears to be distorted by a large photospheric region of unbalanced magnetic flux.

Alternative methods for obtaining the structure of the heliospheric current sheet in the early portion of Sunspot Cycle 21 have recently been described in this journal. Hoeksema et al. (1982) used the line-of-sight observations of the photospheric magnetic field at the Stanford Solar

Observatory together with a potential field approximation to compute the magnetic structure on a spherical source surface at 2.35 $R_{\odot}$. Bruno et al. (1982) have determined the shape of the heliospheric current sheet from a "maximum brightness curve" drawn on synoptic maps of the coronal polarization brightness measured at the Mauna Loa Observatory. The details of each of these methods and complete references to earlier work on this subject can be found in the two papers just cited. The purpose of this note is to compare the results obtained from the two methods.

Figure 1 (adapted from Figure 3 of Hoeksema et al., 1982) shows the intersections of the current sheet with a sun-centered sphere as:

(1) computed by Hoeksema et al. (1982) using the potential field (PF) method (solid lines on the figure), and

(2) inferred from the "maximum brightness curves" (MBC) by Bruno et al. (1982) for 6 solar rotations (dashed lines on the figure).

Each succeeding base line (solar equator) is displaced by 45° heliographic latitude. The + and - symbols represent daily values of the IMF polarity observed at Earth allowing for an average 5 day transit time of solar wind from Sun to Earth. These symbols are plotted at the heliographic latitude of the Earth. When the Earth is north of the current sheet the IMF polarity is predicted to be away from the Sun (+), and when the Earth is south of the current sheet the predicted polarity should be toward tne Sun (-).

The general impression from Figure 1 is that the two methods lead with very similar shapes and with similar amplitude displacements from the solar equator. For five of the six Carrington rotations to which both methods have been applied, the two methods are about equally successful in predicting the observed IMF polarity.

The major disagreement in the current sheet geometries predicted by the two methods occurs on Carrington Rotation 1644. The sheet derived by the PF computation in an interval of longitude centered near 110° is much farther north than on either the preceding or following rotations; the IMF polarity traced back to this longitude range is not consistent with this prediction. In contrast, the current sheet inferred by the MBC method does not show such a northward bulge and is in better agreement with the observed IMF polarity. It should be recalled that the PF computation is based on magnetic observations made near central meridian passage while the MBC inference is based on coronal observations made at the solar limb. The two techniques cannot be expected to agree when the magnetic field and/or coronal structure vary significantly on the time scale separating the observations. Hoeksema et al. (1982) attributed the northward bulge in the PF current sheet to an unusually large photospheric region of unbalanced "toward" polarity that was observed on Rotation 1644 but not on the preceding or following rotations. Thus the major disagreement between the two methods is readily understood.

It is instructive in Figure 1a to look at the longitude interval around 225° on successive rotations. In the first rotations the Earth is north of the current sheet and the IMF polarity is away from the Sun as expected. In Rotation 1645 when the Earth is just north of the current sheet the IMF polarity is away, while on the following rotation when the Earth is just south of the current sheet the IMF polarity is toward. This situation continues on several following rotations. At least during this interval both methods have led to current sheets whose position in latitude corresponds well with the observed polarity of the IMF when the prediction is very sensitive to the precise location and when the sheet is changing slowly (in contrast to Rotation 1644) with time.

An earlier computation of the PF current sheet by Wilcox et al. (1980) that did not include added solar polar magnetic field led to a current sheet whose extent in latitude was too large, as pointed out by Burlaga et al. (1981). The influence on the PF current sheet of added solar polar field is discussed by Hoeksema et al. (1982) and shown in their Figures 5 and 6.

As the coronal structure becomes more complex near sunspot maximum the MBC current sheet cannot be easily determined. PF current sheets from sunspot minimum in 1976 to the present time can be computed using a polar field strength derived by the method of Svalgaard et al. (1978). We believe that this method will continue to yield valid predictions of current sheet geometry and will test these predictions in a future study.

Acknowledgements

We thank our collaborators R. Bruno, L.F. Burlaga, J.T. Hoeksema and P.H. Scherrer for many contributions to this work. This work was supported in part by the Office of Naval Research under Contract N00014-76-C-0207, by the National Aeronautics and Space Administration under Grant NGR05-020-559 and Contract NAS5-24420, by the Atmospheric Sciences Section of the National Science Foundation under Grant ATM77-20580 and by the Max C. Fleischmann Foundation.

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Figure Caption

Figure 1(a/b). The solid lines are the heliospheric current sheet computed with a potential field approximation on a source surface at 2.35 $R_{\odot}$ on nine successive Carrington Rotations, 1641-1649, beginning on 30 April 1976 to 4 December 1977 (after Hoeksema et al., 1982). The dashed lines show the heliospheric current sheet as inferred from observations of coronal polarization brightness by Bruno et al. (1982). Each succeeding base line (solar equator) is displaced by 45° heliographic latitude. The + and - symbols represent daily values of the IMF polarity observed at Earth allowing for the five day transit time of solar wind from Sun to Earth. These symbols are plotted at the heliographic latitude of the Earth. On the solid line significant disagreements between the predicted and the observed IMF polarities are indicated with a thicker line.

HELIOSPHERIC CURRENT SHEETS

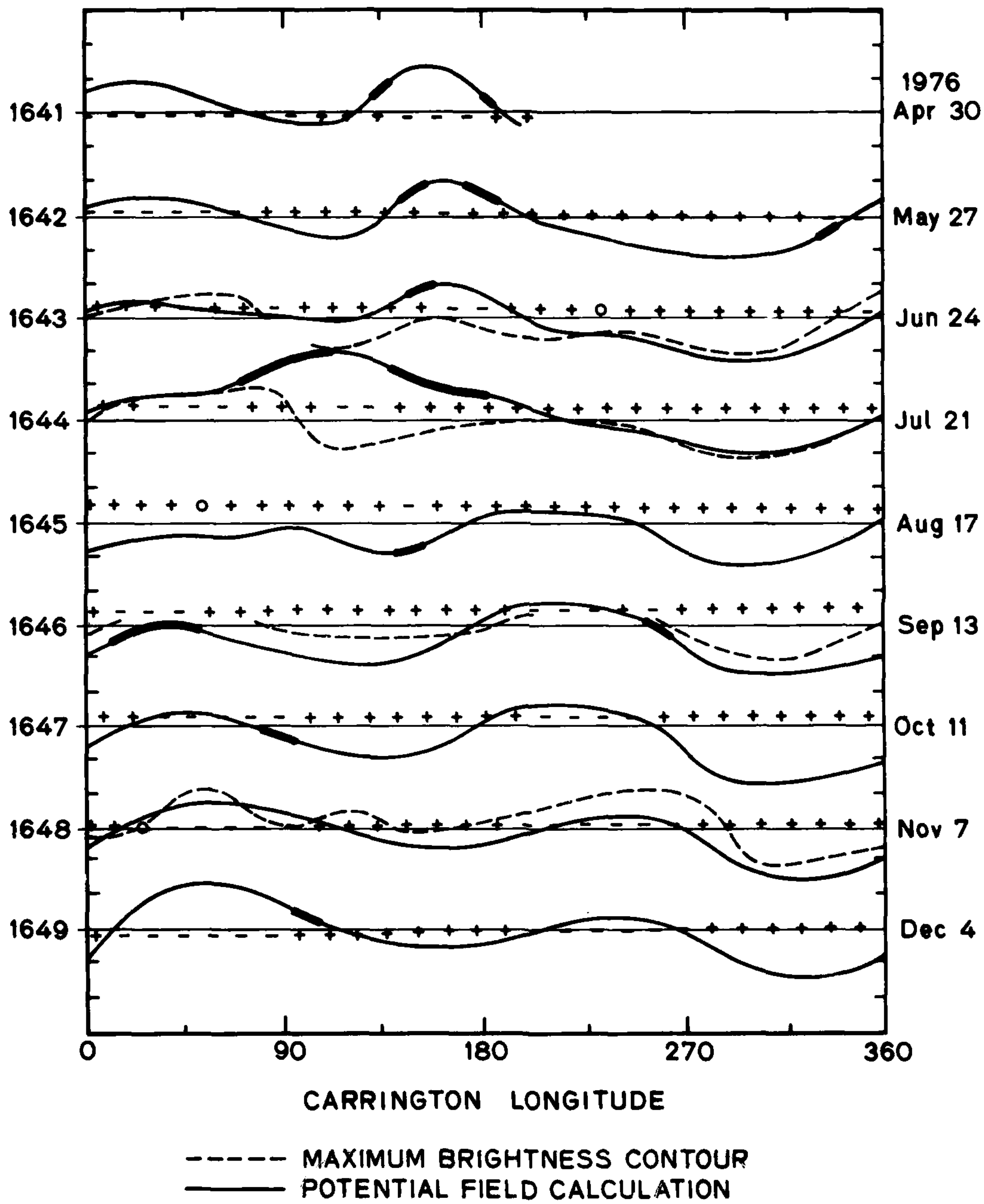

Fig. 1a.

HELIOSPHERIC CURRENT SHEETS

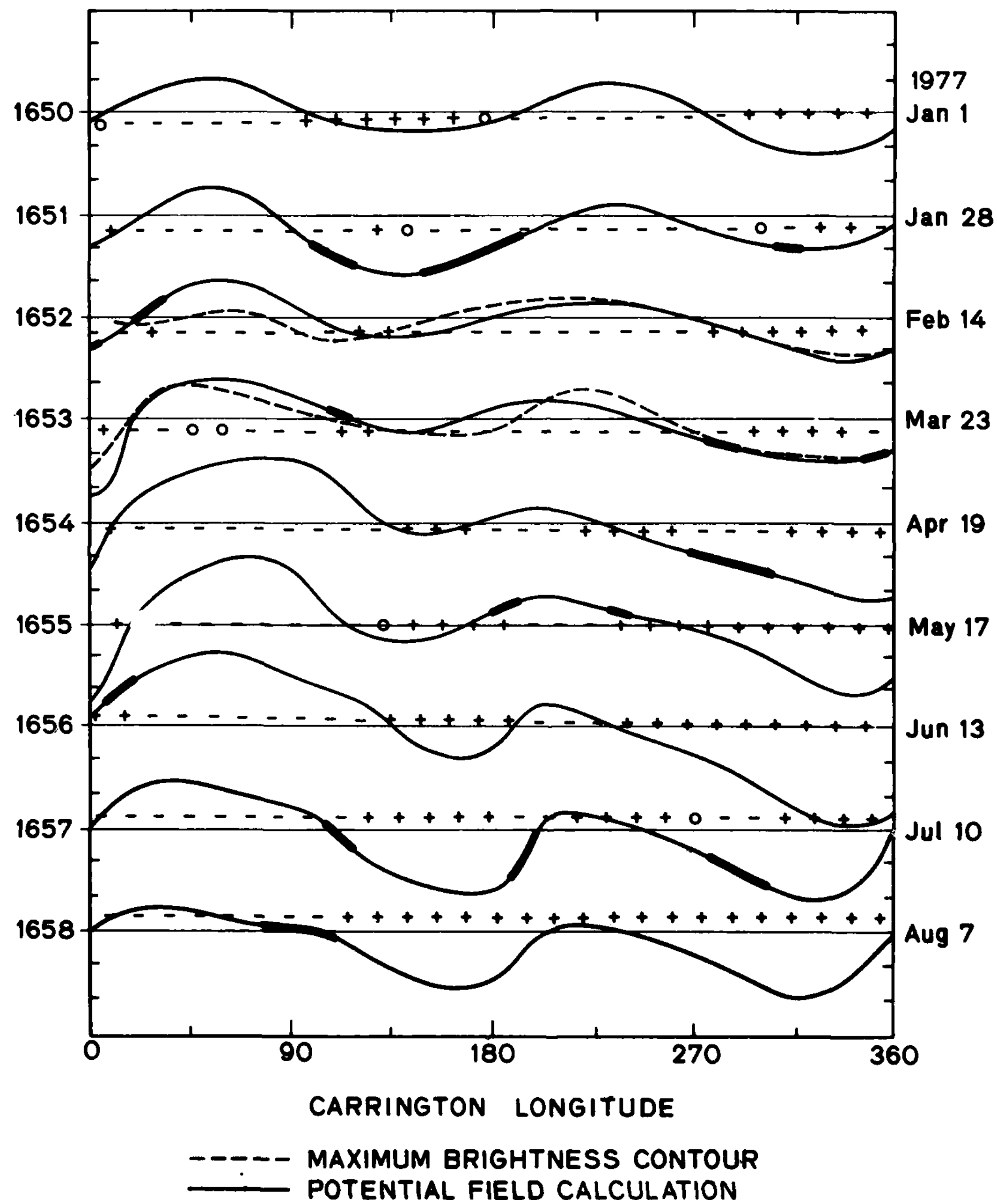

Fig. 1b.

Structure of the Heliospheric Current Sheet in the Early Portion of Sunspot Cycle 21

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Structure of the Heliospheric Current Sheet in the Early Portion of Sunspot Cycle 21

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The structure of the heliospheric current sheet on a spherical source surface of radius 2.35 R_S has been computed via the use of a potential field model during the first year and a half after the last sunspot minimum. The solar polar magnetic field that is not fully observed in conventional magnetograph scans was included in the computation. The computed heliospheric current sheet had a quasi-stationary structure consisting of two northward and two southward maxima in latitude per solar rotation. The extent in latitude slowly increased from about 15° near the start of the interval to about 45° near the end. The magnetic field polarity (away from the sun or toward the sun) at the subterrestrial latitude on the source surface agreed with the interplanetary magnetic field polarity observed or inferred at the earth on 82% of the days. The interplanetary field structure observed at the earth at this time is finely tuned to the structure of low-latitude fields on the source surface.

1. INTRODUCTION

Almost daily observations of the large-scale photospheric magnetic field structure were started at the Stanford Solar Observatory in May 1976 and have continued to the present time. We compute the large-scale structure of the magnetic field in the heliosphere by using Zeeman observations of the line-of-sight component of the photospheric magnetic field along with a potential field model. It is also possible to infer the structure of the heliospheric current sheet from the maximum brightness contours in the K coronameter observations at Mauna Loa Observatory [*Burlaga et al.*, 1981, and references therein].

During the time interval considered here, there was an electric current sheet that was warped northward and southward of the plane of the solar equator [*Schulz*, 1973]. North of the current sheet, the interplanetary magnetic field (IMF) was directed away from the sun, and south of the current sheet, the IMF was directed toward the sun.

The minimum between sunspot cycles 20 and 21 occurred in June 1976. During the 18 Carrington solar rotations begun in May 1976, the computed current sheet was quasi-stationary, having in each solar rotation two northward and two southward extensions. This usually produced the characteristic four-sector structure in the interplanetary magnetic field observed at the earth [*Svalgaard and Wilcox*, 1975]. Occasionally during a rotation, one, or even both, of the northward extensions of the current sheet 'missed' the earth, resulting in a two-sector, or even a 'zero' sector structure being observed at the earth. Around sunspot minimum the maximum extent in latitude of the computed current sheet was about 15°, while by the end of the 18 solar rotations discussed here the maximum latitude had increased to about 45°. Just after the time interval discussed here the maximum latitude of the current sheet increased further and the quasi-stationary structure of the current sheet began to change, so that September 1977 seems a natural point to end the present investigation. The structure of the computed heliospheric current sheet in later portions of sunspot cycle 21 will be discussed in future papers.

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We also investigate here the effect of varying the source surface radius, the strength of the polar field correction, and the latitude on the source surface used to predict the IMF polarity seen at Earth.

COMPUTATION OF THE SOURCE SURFACE

Schatten et al. [1969] and *Altschuler and Newkirk* [1969] introduced the concept of a potential field model with a spherical source surface that surrounded and was concentric with the sun [see also *Levine and Altschuler*, 1974; *Poletto et al.*, 1975; *Altschuler et al.*, 1976; *Adams and Pneuman*, 1976; *Svalgaard and Wilcox*, 1978 and *Riesebieter and Neubauer*, 1979]. Outside the source surface it is assumed that the radial flow of the solar wind carries the magnetic field outward into the heliosphere. Between the photosphere and the source surface it is assumed that the magnetic field can be described in terms of a potential that satisfies Laplace's equation. For the work described here the inner boundary condition at the photosphere is the line-of-sight magnetic field observed at the Stanford Solar Observatory. The outer boundary condition is that the field is normal to the source surface, consistent with the assumption that it is then carried outward by the solar wind. The assumption in the source surface calculation that there are no currents would not be very good for the strong localized fields of an active region, but for the large-scale, quasi-stationary fields that dominate the present analysis the source surface gives a reasonably good prediction of the polarity of the interplanetary magnetic field observed at the earth.

A nonspherical source surface computation [*Schulz et al.*, 1978; *Levine et al.*, 1982] should give an improved prediction of the coronal structure and of the IMF observed at the earth, but as we shall see, the spherical source surface already does quite well at predicting the IMF polarity. The amount of improvement obtained from a nonspherical source surface using our observations will be investigated in a later paper. The magnitude of the interplanetary magnetic field may be better computed with nonspherical source surface.

In most previous work the magnetic field on the source surface has been computed only once for each Carrington rotation, i.e., in steps of 360° longitude. This forces the beginning (360°) and the end (0°) of the rotation to have the

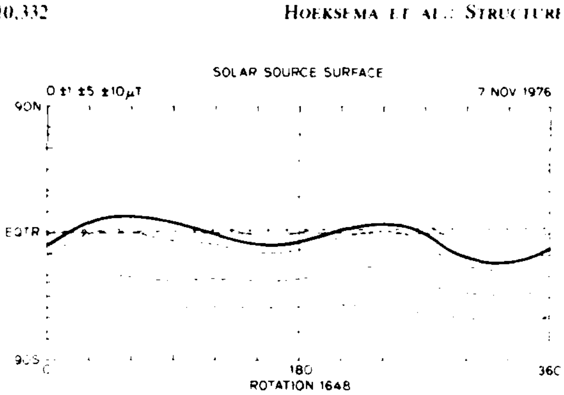

Fig. 1. Computed magnetic field contours on a spherical source surface concentric with the sun at a radius of 2.35 R_S for Carrington rotation 1648, beginning November 7, 1976. The solid contour lines represent field directed away from the sun with observed field strengths 1, 5, and 10 μT; the dashed contours represent field directed toward the sun. The observed field strengths should be multiplied by a factor of 1.8 to account for magnetograph saturation [*Svalgaard et al.*, 1978]. The heavier line near the solar equator is where the direction of the computed field changes from away to toward and is assumed to be the source of the heliospheric current sheet. The + and − symbols represent daily values of the polarity of the interplanetary magnetic field observed at the earth, adjusted for the 5-day transit time of solar wind from the sun to the earth.

same structure, even though they are separated in time by 27 days. To avoid this difficulty we have computed the field on the source surface in steps of 10° in the starting longitude and retained only the central interval of width 30° in longitude from each such computation. As the last step a 1:2:1 averaging of the three calculations for each longitude strip is applied to slightly smooth the structure. In the (rare) case of data gaps we interpolate between the previous and the subsequent rotation.

Stenflo [1971], *Howard* [1977], *Svalgaard et al.*, [1978], *Pneuman et al.* [1978], and *Burlaga et al.* [1981] have pointed out that conventional solar magnetograph observations do not adequately represent the solar polar magnetic field strength. *Wilcox et al.* [1980] computed the heliospheric current sheet configuration early in 1976, using solar magnetograph observations from Mt. Wilson Observatory that were not corrected for the solar polar magnetic field unobserved in daily solar magnetograms. As a result the computed extent in latitude of the heliospheric current sheet was probably too large, as was pointed out by *Burlaga et al.* [1981].

In the present computation of the heliospheric current sheet we use the magnetic field observed at a resolution of 3 arc min in daily scans with the solar magnetograph at the Stanford Solar Observatory, plus the solar polar field strength determined by Svalgaard et al. for the same solar rotations analyzed in the present paper. In the interval analyzed by Svalgaard et al. the magnitude of the solar polar field did not change appreciably. We note that near the minimum of the sunspot cycle the solar polar fields will have the maximum influence. As the sunspot cycle progresses after minimum the strength of the solar polar field decreases, while the strength of the low-latitude fields increases. Near sunspot maximum, when the polarity of the solar polar fields is changing, most of the heliosphere may be dominated by the lower-latitude magnetic fields.

The Computed Heliospheric Current Sheet

The radial magnetic field computed on a spherical source surface at 2.35 R_S for Carrington rotation 1648, beginning November 7, 1976, is shown in Figure 1. The current sheet is represented by the zero contour shown as a thick solid line near the equator. The solid contours above it represent field directed away from the sun of magnitudes 1, 5, and 10 μT, while the dashed contours represent field directed toward the sun with the same contour levels. The predominance of away polarity magnetic field in most of the northern region of the heliosphere and of toward field in most of the southern heliosphere is apparent in Figure 1.

The + (away from the sun) and − (toward the sun) symbols in Figure 1 represent daily polarities of the interplanetary magnetic field at the earth, as observed by spacecraft [*King*, 1979*a*] or, when spacecraft observations were not available, as inferred from polar geomagnetic observations [*Svalgaard*, 1973]. The IMF polarities at the earth that are plotted in Figure 1 have been displaced by 5 days, corresponding to the average transit time of solar wind from the sun to the earth near the times when the large-scale magnetic polarity changes (sector boundaries). The average magnitude of this transit time during the solar rotations studied here has been determined by a cross-correlation analysis, which will be described later. We note that near the sector boundaries the velocity of the solar wind is almost always near a minimum [*Wilcox and Ness*, 1965], so that this transit time is longer than the average solar wind transit time.

Figure 2, in the same format as Figure 1, shows the field computed at the source surface for Carrington rotation 1656, beginning June 13, 1977. The extent in latitude of the computed current sheet had increased to about 40°, but the same property of two northward and two southward excursions in the current sheet (a four-sector structure) was still evident.

Figure 3(*a*, *b*) shows the computed current sheets and IMF polarities observed at the earth during the 18 solar rotations considered in the present work. In every rotation except number 1644 there were two northern and two southern extensions of the current sheet, corresponding to a basic four-sector structure. In rotation 1645 the computed current sheet was everywhere southward of the heliographic latitude of the earth, and the IMF polarity observed at the earth was almost entirely away from the sun. Presumably, this is an example of the situation discussed by *Wilcox* [1972] in which near the last five (now six) sunspot minima the observed or inferred IMF polarity has been largely away from the sun during a few consecutive rotations. If the current sheet 'misses' the earth near the time of a sunspot minimum, the

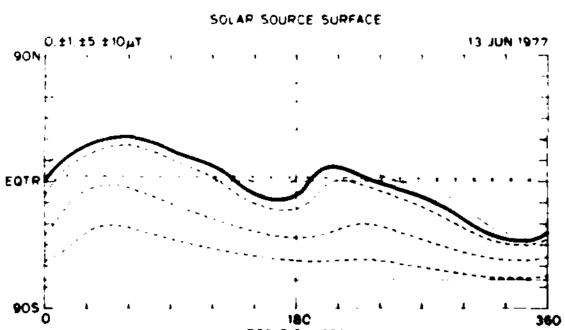

Fig. 2. The same format as Figure 1 but for a later Carrington rotation, 1656, beginning June 13, 1977. Note that the latitudinal extent of the computed heliospheric current sheet extends to higher latitudes than in Figure 1.

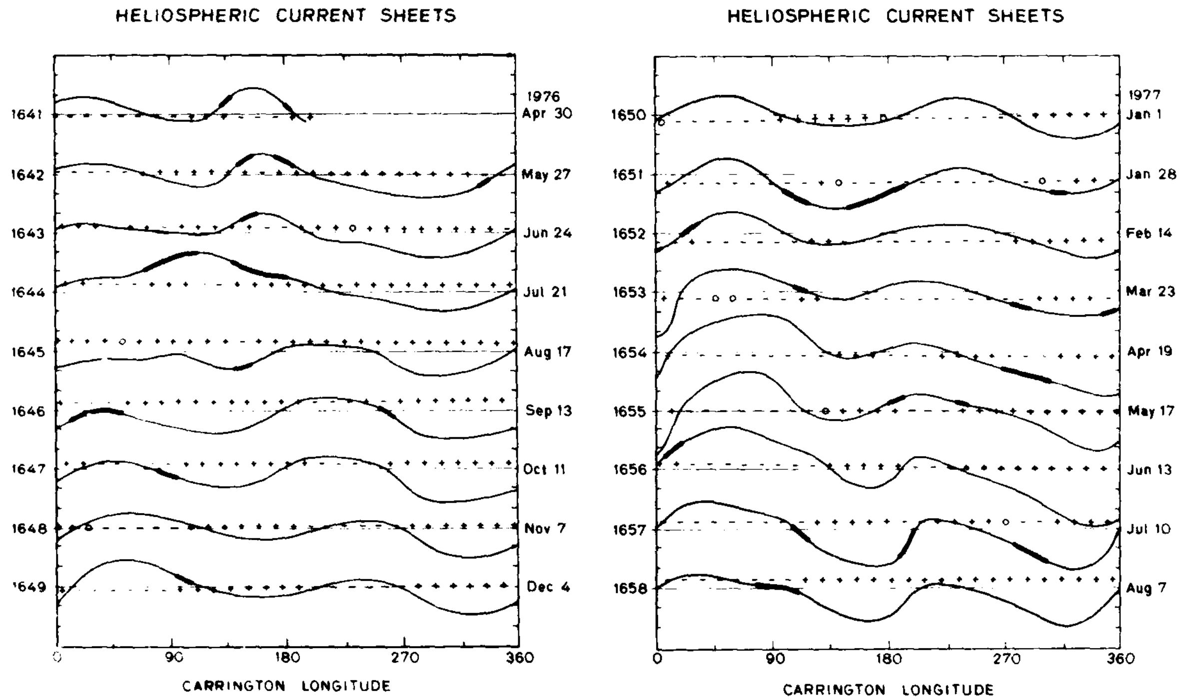

Fig. 3. (*a*) The heliospheric current sheet computed on a source surface at 2.35 R_S on nine successive Carrington rotations, 1641–1649, beginning on April 30, 1976, to December 4, 1977. Compare for example the current sheet shown here for Carrington rotation 1648 with that shown in Figure 1. Each succeeding baseline (solar equator) is displaced by 45° heliographic latitude. The + and − symbols represent daily values of the IMF polarity observed at the earth, allowing for the 5-day transit time of solar wind from the sun to the earth. Significant disagreements between the predicted and observed IMF polarities are indicated with a thicker neutral line. (The first rotation is near sunspot minimum.) (*b*) The same as Figure 3*a* but for the next nine Carrington rotations, 1650–1658, beginning January 1, 1977, to August 7, 1977. Note that the extent in latitude of the computed current sheet increases in the later rotations.

resulting predominant polarity of the IMF could be either away from or toward the sun, according to the considerations discussed in this paper. A predominance in away polarity in the observed photospheric field, also discussed by *Wilcox* [1972], would not necessarily be directly related to the situation shown here in rotation 1645.

Hundhausen [1977] noted that a 'monopolar' sector structure, as seen in rotation 1645 of Figure 3*a*, might appear at the beginning of a new solar cycle. However, the suggestions that at this time 'the prominent recurrent sectors, streams and geomagnetic activity sequences should end abruptly' and the 'recurrence with the 27-day solar rotation period should become rare' are not consistent with the computed current sheets in Figure 3(*a*, *b*).

In rotation 1658 the computed current sheet had a clear 'four-sector' structure, but was sufficiently far south of the heliographic latitude of the earth that only a two-sector structure was observed here. This appears to be the same geometry but the opposite sense from the situation in early 1976 described by *Scherrer et al.* [1977].

From the start of Figure 3*a*, near the minimum of the 11-year sunspot cycle, to the end of Figure 3*b*, 1.5 years later, the maximum extent in latitude of the computed current sheet increased from about 15° to about 45°. This increase is qualitatively similar to but larger than the average variation computed by *Svalgaard and Wilcox* [1976] through the previous four sunspot cycles.

Burlaga et al. [1981] noted that for Carrington rotations 1639 and 1640, just before the start of the interval shown in Figure 3*a*, a solar dipole magnetic axis tilted about 20° to 15° with respect to the solar rotation axis cannot explain the sector pattern observed by Helios. The sector patterns shown in Figure 3*a* and *b* during 1.5 years after the rotations discussed by Burlaga et al. also cannot be explained with a tilted dipole, as was proposed by *Smith and Tsurutani* [1978], *Villante et al.* [1979], *Smith and Wolfe* [1979], *Zhao and Hundhausen* [1981], and *Hakamada and Akasofu* [1981].

On most of the rotations during 1976, shown in Figure 3*a*, the current sheet extended more into the southern heliosphere (the case of rotation 1644 is discussed below), consistent with the results of *Wilcox et al.* [1980], *Burlaga et al.* [1981], and *Villante et al.* [1982]. The conjecture of *Villante et al.* [1982] that the current sheet during the first half of 1977 was confined in a narrower latitude region is not consistent with the current sheets shown in Figure 3*b*.

In Figure 3*a* and *b*, intervals of significant disagreement between the IMF polarity predicted by the computed current sheet and that actually observed are indicated by a bar attached to the current sheet. We note that for the most part the daily polarity of the IMF observed at the earth is quite well predicted by the computed current sheet; in fact there is agreement on 82% of the days.

A conspicuous disagreement is associated with the rapid change in the computed current sheet from one rotation to the next at rotation 1644. This change in the computed current sheet was caused by the appearance of a particularly large bipolar magnetic region in the photosphere. Figure 4*a*,

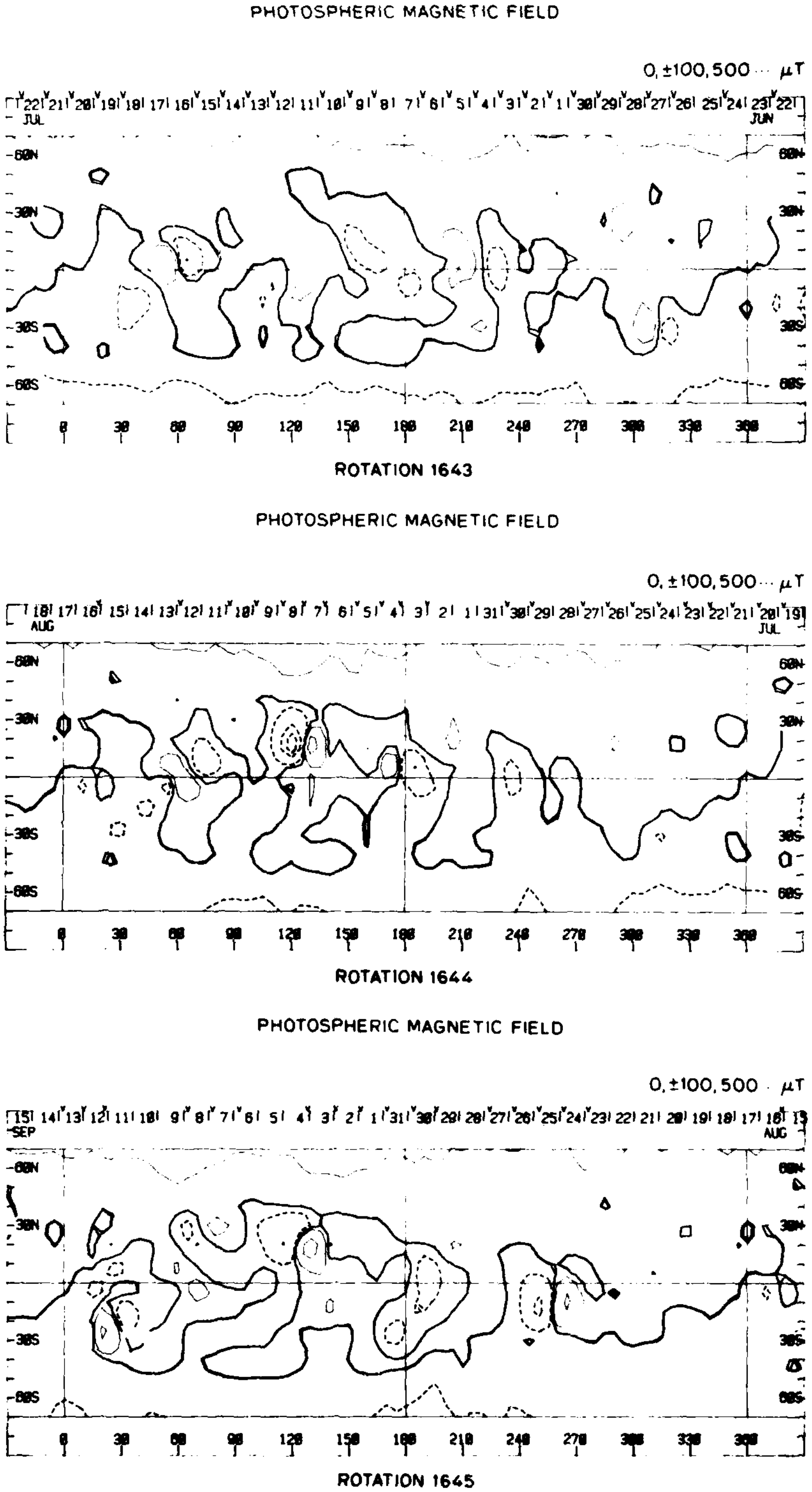

Fig. 4. (*a*) A synoptic map of the line-of-sight photospheric magnetic field measurements observed at the Stanford Solar Observatory for Carrington rotation 1643. The dates indicate the central meridian passage time for corresponding longitude. The inverted carets show the dates of magnetograph scans that contribute to the chart. (*b*) The same format as Figure 4*a* for Carrington rotation 1644. Notice the large active region that has appeared in the northern hemisphere near longitude 120. (*c*) Synoptic chart for Carrington rotation 1645. The size and strength of the active region is greatly reduced.

b, and *c* shows synoptic charts of the observed photospheric magnetic field for rotations 1643, 1644, and 1645. A large bipolar magnetic region appeared in rotation 1644 at longitude 120° with predominantly toward polarity field. The corresponding IMF polarity observed at the earth was away on several days, during which the computed current sheet would lead to a prediction of toward. It seems possible that there may have been a region of toward magnetic field polarity in the heliosphere corresponding to this bipolar magnetic region but at a latitude sufficiently far north as not to intersect the earth. A similar event occurred near 140° longitude in the southern hemisphere in Carrington rotation 1651.

The rather rapid change in the computed current sheet near longitude zero from rotations 1652 to 1653 was also caused by the appearance of a large bipolar magnetic region in the photosphere, but in this case the region remained in the photosphere for several rotations, and the corresponding effects on the computed current sheet also continued for several rotations.

In many of the rotations shown in Figure 3*a* and *b* the latitude of the current sheet at the end of the rotation is significantly different from the latitude at the start of the rotation. This illustrates the advantage gained from computing the field structure on the source surface at steps of 10° in the starting longitude, since if only one computation were made for each rotation the latitude of the current sheet at the start and the end of the rotation would be forced to be the same.

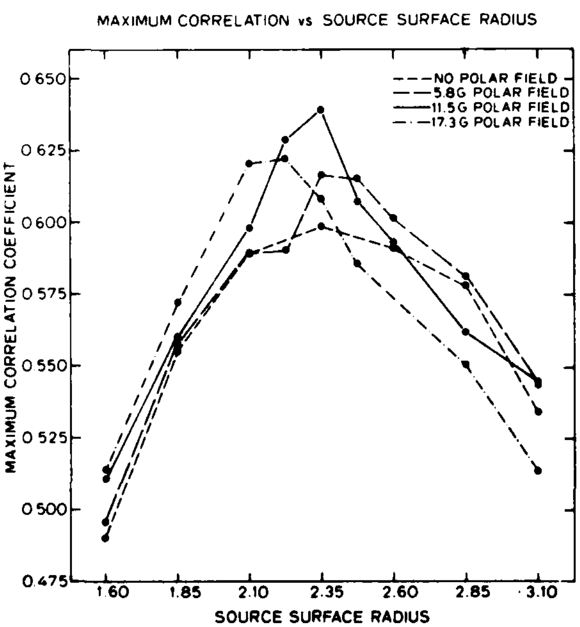

Fig. 5. Maximum correlation between the IMF polarity predicted from the computed heliospheric current sheet and the IMF polarity observed at the earth as a function of the source surface radius on which the current sheet was computed. Source surfaces were computed with an added solar polar field strength of 11.5 G, as computed by *Svalgaard et al.* [1978], and for other values of the added solar polar field as shown.

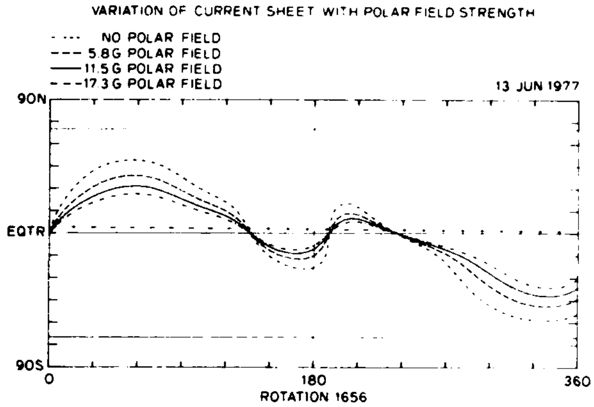

Fig. 6. Computed heliospheric current sheets on Carrington rotation 1656, beginning June 13, 1977, for several values of added solar polar magnetic field. As the strength of the polar field is increased, the computed current sheet approaches the plane of the solar equator.

Influence of the Solar Polar Field Strength and the Radius of the Source Surface

The source surface current sheet was computed in the above discussions by using the solar polar field strength of the form $11.5 \cos^8 \theta$ G, derived by *Svalgaard et al.* [1978], where θ is the colatitude. We will now investigate the effect of changing the magnitude of the derived solar polar field and of changing the radius of the source surface. For this purpose we will compute a cross correlation between the IMF polarity predicted from the computed current sheet and that actually observed or inferred at the earth.

In order to determine the predicted IMF polarity a line is drawn on the source surface at the heliographic latitude of the earth, i.e., varying from 7°N to 7°S through the year. This line is divided into daily increments, and on a given day, if the current sheet is southward of the line, the predicted polarity is away, and if the current sheet is northward of the line, the predicted polarity is toward the sun. At least 5/8 of a day must have the same polarity in order for a polarity to be assigned. The solid curve in Figure 5 shows the maximum cross correlation between the predicted IMF polarity described above and the polarity observed at the earth as a function of the radius of the source surface on which the current sheet is computed, using the polar field strength computed by Svalgaard et al. The largest correlation occurs for a source surface of radius 2.35 R_S, and this radius has therefore been chosen for most of the discussion in this paper. For comparison, Figure 5 also shows similar maximum cross correlations for source surfaces computed with no polar field added and for 5.8 G and 17.3 G added polar field. We note that the solar polar field of 11.5 G, computed by Svalgaard et al., does give the best agreement, although the differences are not large.

Figure 6 shows computed current sheets on a typical Carrington rotation (i.e., rotation 1656) for the four values of added solar polar magnetic field. The current sheet for the selected value of 11.5 G is shown with a solid line. The current sheet shown with short dashes was computed with no added solar polar field, and it has the largest extent in latitude in Figure 6. The dash-dot line is a current sheet

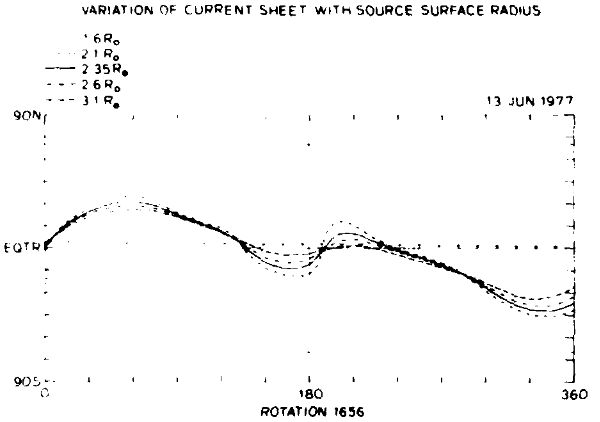

Fig. 7. Computed current sheets for Carrington rotation 1656, beginning June 13, 1977, for source surfaces at several different radii, as indicated. As the radius of the source surface is increased, the computed current sheet approaches the solar equator.

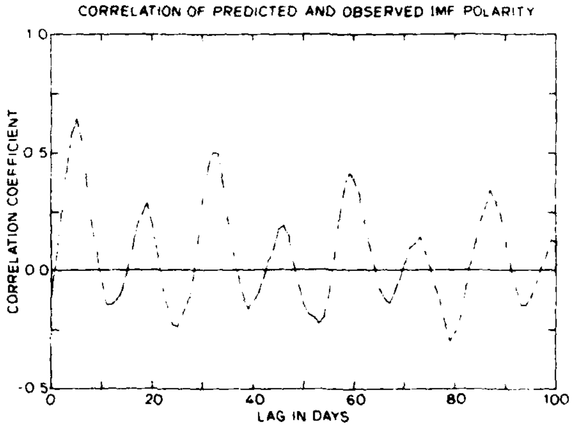

Fig. 9. Cross correlation between the IMF polarity predicted from the adopted computation of the heliospheric current sheet and the polarity observed at the earth. The lag of the first peak is 5 days, which represents the transit time from the sun to the earth of the solar wind near the sector boundaries.

computed with 17.3 G added solar polar field (i.e., 1½ times the preferred value), and it has the smallest extent in heliographic latitude.

Pneuman et al. [1978] computed the field on a source surface at 2.5 R_S during the Skylab period in 1973 and found that their computed neutral lines were systematically poleward of the brightness maxima observed at 1.8 R_S with the K coronameter at Mauna Loa, Hawaii. If the fields above 70° latitude measured with the full-disk magnetograph at Kitt Peak National Observatory were increased to about 30 G, this effect was removed. This is a much larger correction for the solar polar field than we have used. The reason for the difference from our work is not clear. Pneuman et al. suggested other possible causes for their systematic poleward displacement of the neutral line; to the extent that

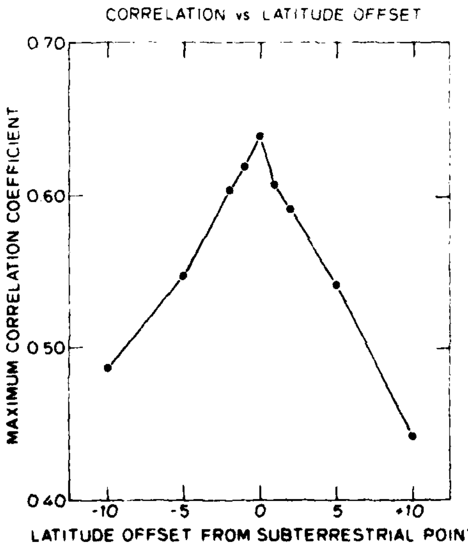

Fig. 8. The maximum cross correlation between the IMF polarity predicted from a computed current sheet on a source surface at 2.35 R_S with 11.5 G added polar field and the IMF observed at the earth, as a function of the latitude on the source surface at which the field polarity was predicted. In the abscissa, zero represents the heliographic latitude of the earth.

these operated, the solar polar field correction would be reduced. A difference in solar magnetograph calibrations between Kitt Peak and Stanford may have contributed to the different corrections, and the solar polar field strength may have been different in 1973 and 1976.

King [1979*b*] reports an average value of about 0.72 for the logarithm of the hourly averaged IMF intensities observed near the earth in 1976 and 1977. This corresponds to a radial component of IMF at the earth of 3.7 nT. A scaling with the square of the radius gives field values of 30 μT at 2.35 R_S and of 170 μT at the photosphere. Our Figures 1, 2, and 4 show the observed field magnitudes, which must be multiplied by 1.8 because of magnetograph saturation effects [*Svalgaard et al.*, 1978]. After this correction an average value of about 3 μT is found for the field in the equatorial regions of the source surface at 2.35 R_S, which is an order of magnitude smaller than the value scaled from the IMF observed at the Earth.

For comparison with the observed photospheric field shown in Figure 4 the above value of 170 μT that was scaled from the IMF observed at the earth should be divided by the magnetograph saturation correction of 1.8, giving about 94 μT. The lowest contour level in Figures 4 is 100 μT, and it is clear that most of the measured photospheric field shown in Figure 4 is less than 100 μT. Thus this field, which was the inner boundary condition for the source surface field computation, was usually smaller than the value obtained by scaling from the earth. The difficult problem of magnetograph calibration and the comparably large observing aperture used at Stanford may account for part of the difference. A further discussion is beyond the scope of the present paper.

The use of a spherical source surface probably causes part of the difference. Using a nonspherical source surface might increase the field strength in equatorial regions.

All the computed current sheets in Figure 6 cross the solar equator at the same longitudes, and the cross correlations shown in Figure 5 are nearly the same for all the values of added solar polar magnetic field. Near 340° longitude the maximum latitude of the current sheet decreases from 58° for no added solar polar field to 37° for 17.3 G added field. All of the computed current sheets in Figure 6 agree almost equally well with the IMF polarity observed at the earth.

The computed current sheet in Carrington rotation 1656 for several values of the radius of a spherical source surface is shown in Figure 7. As the radius of the source surface is increased the latitudinal extent of the computed current sheet decreases, since the relative weight of the dipole component of the solar magnetic field increases. All of the computed current sheets in this rotation agree almost equally well with the observed IMF polarity.

Thus a comparison of the IMF polarity predicted from a computed current sheet with the IMF polarity observed at the earth is a weak test of the latitudinal extent of the computed current sheet. A spacecraft observing at large heliographic latitudes would give the definitive answer to the problem of the latitudinal extent of the heliographic current sheet.

Further Comparison of Predicted and Observed IMF Polarity

In the discussion so far the IMF polarity observed at the earth has been compared with the source surface field polarity at the heliographic latitude of the earth. What happens if, instead, we compare the observed IMF polarity at the earth with the polarity on the source surface 5° north of the subterrestrial latitude? Figure 8 shows that the maximum cross correlation decreases from 0.64 to 0.54. We see in Figure 8 that the subterrestrial latitude on the source surface has the most similar magnetic polarity structure to that observed at the Earth and that even a few degrees north or south of the subterrestrial latitude the correlation with the observed field is smaller.

For the adopted conditions of source surface radius equal to 2.35 R_S and added solar polar field of 11.5 G, Figure 9 shows a cross correlation between the predicted field polarity at the subterrestrial point on the source surface and the IMF polarity observed at the Earth. The first peak at 5.0 ± 0.3 days represents the transit time for the solar wind plasma to transport the magnetic field from the sun to the earth. The 5-day lag corresponds to a solar wind velocity of 350 km/s. This represents the average solar wind velocity at sector boundary crossings, which are usually near minima in solar wind velocity [*Wilcox and Ness*, 1965]. The relatively slow decline in amplitude of the peaks near 32 days, 59 days, and 86 days shows that the large-scale IMF structure is quasi-stationary. The intermediate peaks are caused by the four-sector nature of the IMF structure at this time. The difference in time between the peak at 32 days and at 5 days shows that the recurrence time of the IMF is close to 27 days.

Our final comparison of the structure predicted from the source surface and observed at the Earth is shown in Figures 10 and 11. These figures are now in a Bartels rotation plot, as is customary for geomagnetic observations. Comparison of the figures shows that the large-scale structure is quite well predicted, and most of the disagreements come near sector boundary crossings or on occasional rotations. A portion of the disagreement near boundary crossings is caused by our use of a constant 5-day solar wind transit time from the sun to the earth, while in fact there are some variations among the actual transit times. On the 1-day scale used in plotting Figures 10 and 11 these variations in transit time would not be a large effect.

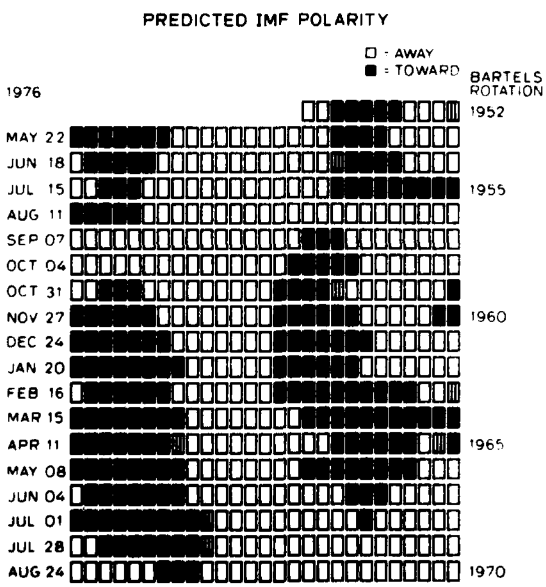

Fig. 10. The IMF polarity computed at the source surface by the model is presented in the Bartels chart format. Each row has 27 boxes, with the polarity for each day indicated in a box. A filled box indicates toward polarity; a hatched box indicates indeterminate polarity; an empty box indicates away polarity. The plot is displaced by 5 days to account for the solar wind transit time from the sun to the earth. This format emphasizes the 27-day recurrence pattern in the polarity and the large-scale structure over many rotations.

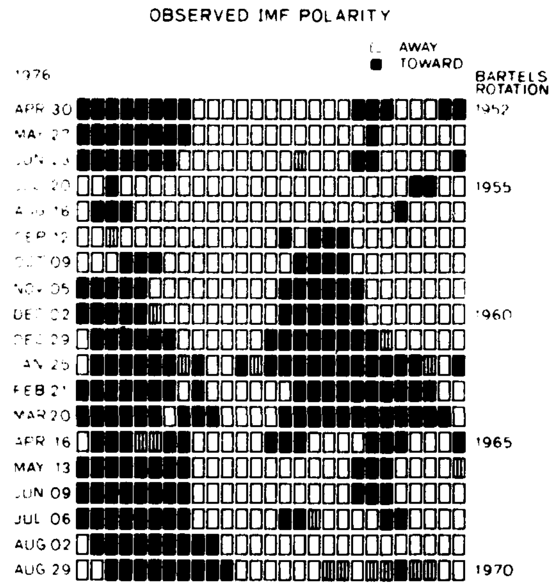

Fig. 11. Same format as Figure 10 but for the IMF polarity observed at the earth.

Summary

The heliospheric current sheet configuration has been computed on a source surface at 2.35 R_S during an interval of 1.5 years after the last sunspot minimum. The magnetic field observed on almost daily scans with the solar magnetograph at the Stanford Solar Observatory has been corrected for the solar polar fields that are not fully observed. This correction significantly reduces the latitudinal extent of the computed current sheet.

The field on the source surface at the subterrestrial latitude agrees best with the interplanetary magnetic field observed at the earth. A deviation from this latitude of more than a few degrees produces a significant decrease in the accuracy of the predicted IMF.

During these 18 rotations, the computed current sheet had a quasi-stationary structure with two northward and two southward excursions per rotation, corresponding to a four-sector structure. Occasionally, an excursion 'missed' the earth. Near sunspot minimum the maximum latitudinal extent of the current sheet was about 15°, but 1.5 years later the maximum latitude had increased to about 45°.

Comparisons with the IMF polarity observed at the earth give only a weak test of the latitudinal extent of the current sheet. The most definitive answer to this question will come from observations with spacecraft at larger heliographic latitudes. Although a large part of the heliosphere is filled with magnetic flux from the solar polar regions, the structure of the IMF observed at the earth is still closely related to the structure of low-latitude fields on the source surface.

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